Do We See the "Dark Clouds" Again? — On Some Puzzles in Contemporary Physics

Guang-jiong Ni*

Department of Physics, Fudan University, Shanghai 200433, P.R. China

Abstract

Some conceptual problems in physics are discussed. Do we need a change in the concept of matter structure? Why the "$i = \sqrt{-1}$" is introduced to quantum mechanics (QM) essentially? What is the relation between QM and special relativity (SR)? Could we modify the stationary Schrödinger equation in conformity with SR? How can a particle acquire a mass? We propose some tentative answer. Their philosophical implications are emphasized.

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[0]*E-mail: gjni@fudan.ac.cn

The cognition of contemporary physics penetrates, on the one side, into the microscopic world at the scale of 10^{-17} cm; on the other hand, it expands to the universe at the scale of 10^{10} light year, i.e., 10^{28} cm. Meanwhile, it permeates actively into the various fields of science and technology and play an immense role in pushing them forward. Now it seems that the pace of progress in physics itself is not as rapid as that in its applications. so the problems is how could we speculate about the further development of physics in the next century.

In this paper, I would like to join the discussion of this problem from personal point of view.

1. Do we see the “dark clouds” again?

In 1900, the British physicist Kelven (W. Thomson) had thought that the mansion of classical physics was basically established, the work left for the physicists in 20th century would be just mending. but he said again: “In the remote part of sunny sky of physics, there are two small puzzling dark clouds”. He referred to the Michelson-Morley experiment and the experiments on black-body radiation. As was well known, from these two dark clouds emerged the theory of relativity and the quantum theory. The above story had been cited for many times (e.g. [1]). However, now I doubt whether it could reflect the overall situation at that time. The physicists (including Kelven), who had good eyesight, should not fail to pay attention to the three successive discoveries in three years 1895-1897, the X ray, radioactivity and electron. They actually raised the curtain of symphony of physics, even the whole science and technology in the 20th century.

The so called dark clouds imply serious conflict between the new experimental facts and existing theory. it seems that the contradictions encountered in present day physics is not so clearcut or acute as that occurred 100 years ago. but at least there are four puzzles which are generally recognized.

1.1. Why the quarks can not escape from hadrons? (the puzzle of quark confinement).

1.2. After the discovery of parity violation in 1956, the violation of CP (i.e. T) invariance was discovered in 1964. But the extent of violation is only 0.3%. What does it mean?

1.3 The quasars discovered since the sixties in astronomy are characterized by their small volumes, high luminosities and strange phenomena in the change of luminosity. No satisfying explanation has been found for them.

1.4. The luminous matter only comprise the minority part of the universe. the majority part of universe is composed of dark matter. What are they?

I wish to add a theoretical problem generally emphasized:

1.5. What is the essence or origin of mass?

Another theoretical problem may not be so generally established:

1.6. What is the essence of special relativity (SR)? What is the relation between SR and quantum mechanics (QM)?

In the following, due to my lack of knowledge in 1.3 and 1.4, only the other four problems will be discussed.

2. “Why an electron can not fall inside?” and “Why the quark can not escape outside?”.

In comparison with the consideration about various possibilities beyond the

standard model (SM) in particle physics by some theoretical physicists, my point of view is rather conservative. I suggest that the first thing should be to digest so profound achievements of the 20th century physics. In ancient China, Confucius had said that“ to gain new insights through restudying old materials”.

For instance, a fact which forms an acute contrast to problem 1.1 occurred at the beginning of this century. “ Why an electron can not fall into the nucleus under its attraction?” It was precisely the deep thinking on puzzle of “atom stability” which prompted N. Bohr to propose his quantum model of atom in 1913. After the establishment of QM by Heisenberg, Schrödinger et al. around 1924, one realized that it is the “uncertainty relation” reflecting the “wave-particle dualism” which ensures the stability of atom. When a particle is compressed, its energy increases. The stronger the attraction force is, the stronger its “repulsion” against the compression will be.

Now look at the collision between e^+ and e^- in a collider, say in the BEPC in Beijing. When the energy in the system of center of mass reaches 3.097 GeV, a particle J/ψ may be created. $J/\psi = (c - \bar{c})$ is considered as a binding state of quark c and anti-quark $\bar{c}$. However, either c or $\bar{c}$ can not be found in isolated state till now. For example, if the energy is enhanced to 2×1.869 GeV, the bond connecting c and $\bar{c}$ is broken, but a pair of d quark, d and $\bar{d}$ are created immediately. What we see are two separated D mesons, $D^+ = (c\bar{d})$ and $D^- = (\bar{c}d)$.

So the “quark confinement” together with the emergence of quark-antiquark pair shows a qualitative change in the concept of structure of matter. In the past, if two particles a and b are combined into a composite particle A with binding energy B being much smaller than the rest energy E_0, we can say that a and b are constituent particles or “building blocks” in A=(ab). This is because the difference between the binding state of a or b in A and the free state after separation is small($B/E_0 \ll 1$) . One could often neglect the difference. Now the situation is no longer true. The fact of “quark confinement” tells us that the structure of matter is essentially not piled up by particles but a structure of something else [2].

It is intimately related to problem 1.5. The rest mass of e^+ or e^- is only 0.511 Mev, less than 1.65×10^{-4} of J/ψ mass. So J/ψ is not hiding inside the e^- or e^+, but is excited out of vacuum during the collision. But what object is excited? In our opinion, it is nothing but the “fundamental contradictions” in the nature. The important thing is: a “contradiction” is massless and invisible before it is excited. This was a conjecture by G.W.F. Hegel and F. Engels, now is actually verified by experiments in physics [3].

It seems to us that only the concept of “contradiction” is capable of grasping, in 100 years time span, two features of matter structure — “Why an electron can not fall into nucleus?” and “why the quark can not escape from a hadron?” they seems opposite but virtually are complementary to each other. As this kind of concept is beyond the scope of usual atomism familiar to western physics community, physicists had underestimated the “repulsiveness” of contradiction again and again, now are still underestimating the “identity” of it.

3. The theory of “primary gas” and new “ether”.

For further exploiting the above point of view , let us return back to QM. The

wave function of a free particle with momentum $\vec{p}$ and energy E is described by

$$\psi \sim exp[\frac{i}{\hbar}(\vec{p}\cdot\vec{x} - Et)] \tag{1}$$

In our explanation, being an abstract representation of contradiction between particle and its environment [1], ψ consists of two parts:

$$\psi = Re\psi + iIm\psi \tag{2}$$

Under a phase transformation, it reads:

$$\psi \to \psi^{'} = e^{i\theta}\psi \tag{3}$$

$$\begin{aligned} Re\psi &\to Re\psi^{'} = \cos\theta Re\psi - \sin\theta Im\psi \\ Im\psi &\to Im\psi^{'} = \sin\theta Re\psi + \cos\theta Im\psi \end{aligned} \tag{4}$$

Note that: (a) Both Reψ and Imψ are real, but they are all nonobservables. (b) The distinction between them is necessary. One side regards the existence of other side as the premise of existence of itself. They are indivisible. Any one of two sides can not exist individually. (c) They can be transformed each other as shown in Eq.(4) while keeping $|\psi|^2$ invariant.

In Ref.[4] (earlier by Schwinger et al. [5]), it was pointed out that for an antiparticle with momentum $\vec{p}$ and energy $E(>0)$, the wave function should be written as:

$$\psi_c \sim \exp[-\frac{i}{\hbar}(\vec{p}\cdot\vec{x} - Et)] \tag{5}$$

Accordingly, a particle is not absolutely pure. The ingredient of "antiparticle state" hiding inside will increase with the velocity of particle. then the mass-energy relation $E = mc^2$ can be derived.

We would like to add that mass is a low energy phenomenon familiar in daily life. So its origin, i.e. the essence of $E = mc^2$, must be stemming from one (not two) universal, simple but subtle law, which in turn must be already contained in existing experimental and theoretical knowledge. As a contrast, when Einstein established the SR, he even did not mention the Michelson-Morley experiment explicitly. When Einstein further established the general relativity, besides the SR and the gravitational law, he was mainly depending on the experimental fact that " all freely falling body on the earth have the same acceleration $g \approx 9.8m/sec^2$" which was seen by every one.

The postulate implied in Eqs. (1) and (5) is really very simple and universal — "space-time inversion ($\vec{x} \to -\vec{x}$, $t \to -t$) is equivalent to particle-antiparticle transformation". Basing on this fundamental symmetry, we derived a "relativistic stationary Schrödinger equation for many particle system" [6] with eigenvalue ϵ related to the binding energy B of system as

$$B = Mc^2[1 - (1 + \frac{2\epsilon}{Mc^2})^{1/2}] \tag{6}$$

($M = \sum_{i=1}^{n} m_i$), showing the consistency between SR and QM in essence. It is well known in QM that the operators for particle read (see Eq. (1))

$$\vec{p} \to -ih\nabla, E \to ih\frac{\partial}{\partial t} \tag{7}$$

Now Eq.(5) implies that for an antiparticle:

$$\vec{p}_c \to ih\nabla, E_c \to -ih\frac{\partial}{\partial t} \tag{8}$$

According to the theory of "primary gas" (Yuan-qi) in Chinese philosophy [7], Reψ and Imψ could be named as "yin" (feminine or negative) and "yang" (masculine or positive). Eqs. (1) and (5) show that two opposite coupling modes of them correspond to particle and antiparticle. In 1905, the old theory of "ether" was abandoned for establishing SR. It seems to us that the revival of new theory of "ether" basing on "Yuan-qi" is inevitable. Now it is the time to combine two kinds of wisdom of both eastern and western philosophy.

4. Is there an "arrow of time"?

In defining the so called time reversion (T) in QM, one not only sets $t \to -t$, but also takes a complex conjugation: $\psi \to \psi^*$, for ensuring the invariance of Schrödinger equation. Hence, actually, it implies an equivalence:[8]

$$\psi(\vec{x}, t) \sim \psi^*(\vec{x}, -t) \tag{9}$$

Obviously, the usual stationary(eigen) state does satisfy Eq.(9). The discovery of CP (i.e. T) violation in neutral K system since 1964 has a possible explanation within the framework of SM. If the eigenstate of quark in strong interaction not coincides with that in weak interaction, they are linking together via an unitary transformation, the CKM matrix. Then a phase angle in the matrix may account for the 0.3% discrepancy in CP violation. If this explanation can be further verified in experiments, then the nonconservation of T reversal does mean a peculiar problem in particle physics (there are two kinds of eigenstates for quarks, there exists flavor mixing in the weak interaction eigenstates), but has nothing to do with the basic symmetry in space-time.

C. N. Yang and C. P. Yang had proved that the violation of T reversal has nothing to do with the macroscopic nonreversibility inferred by the second law in thermodynamics [9]. In our point of view, with respect to the problem of time reversal, the so called "Loschmidt paradox" between "microscopic reversibility and macroscopic nonreversibility" does not exist at all. This is because the symmetry discussed in previous section implies that the time reversal must be accompanied by the transformation of matter to antimatter. In some sense, the "arrow of time" already exists at microscopic level. So during the transition from microscopic scale to macroscopic one, instead of the problem that "how can an arrow of time emerge from none", we should ask "how can it display explicitly from implicit existence". We think that the entropy equals zero when a macroscopic system is in a quantum coherent state like that in superconductivity or superfluidity. Once the quantum coherence is destroyed, the entropy increases and the arrow of time emerges explicitly [10].

5. The unity of opposites between individual and its environment.

We set $E = m_0c^2 - i\hbar/2\tau$ in Eq.(1), yielding

$$\psi(t) \sim \exp[-\frac{i}{\hbar}m_0c^2t - \frac{t}{2\tau}], |\psi(t)|^2 \sim \exp(-\frac{t}{\tau}) \tag{10}$$

with τ being the lifetime of particle. Being the "imaginary part of mass", the decay constant $\frac{1}{\tau} = \Gamma$ is determined by its environment. Different nuclei have different life time in Beta decay. Correspondingly, the "real part of mass", m_0, should also depend on its environment. After studying the quantum field theory (QFT) for 40 years, I began to realize that I was totally wrong to think that the observed mass is generated from an intrinsic "bare mass". Now I understand that the calculation of "self-energy" in perturbative QFT has nothing to do with the mass generation. Can we create a mass from a massless model like NJL model [11]? Yes, the outcome turns out to be either no mass scale or two mass scales, but never one mass scale. The reason lies in the fact that besides the mass of particle, another mass scale is needed as a standard weight, which is provided by the phase transition of vacuum(*e.g.* the extra constant $\Lambda \approx 200MeV$ in QCD, being a necessary complement to the Lagrangian, plays the role as a standard weight). [12,13]

We all understand that "Many body system is comprised of individuals. If there is no individual, there is no system". But the above statement merely forms the half of truth. The another half is more important: "The existence of individual is ensured by its environment. If there is no certain environment, there is no certain individual". Chinese philosophy talked about "oneness of heaven and man". It makes sense.

6. Infinity is essentially different from finiteness

The pertubation theory in QFT is expanded with respect to the loop number L in Feynman diagram. The tree level corresponds to L=0. Once the quantum radiation correction is taken into account in L=1, 2, ... calculations, one encounters the divergence, i.e. ∞, immediately. For dealing with it, one devises many tricks like the counter term and bare parameter, etc. I don't believe in these kind of trick any longer. After learning the relevant literatures and beginning from a former graduate student, J-f Yang, we now adopt a new simple trick. Then instead of divergence, we have some arbitrary constants C_i. Neither counter term nor bare parameter is needed. The renormalization is simply to fix these C_i by experiments. So there is also no arbitrary running mass scale (μ) after renormalization, [14-17].

Therefore we begin to realize that the appearance of ∞ is no more than a signal. It is essentially a warning: We expected too much, it is impossible to evaluate the mass or charge in pertubative QFT. Only after we confess that our ability is limited, can we make the target of our theory more clearcut and the latter becomes more predictive. For example, recently we calculated the Higgs mass in SM to be 138 GeV [18], which is in conformity with the outcome of phenomenalogical analysis on present experiments. [19]

Moreover, "∞" is by no means a very large fixed number. If performing the perturbation calculation in QFT to certain order of L, no matter how large it is, we still have perturbative theory, which is not quite different from the tree

level calculation in essence. In particular, the mass of a free particle remains the same. Only after taking L$\rightarrow\infty$, i.e. performing the nonperturbative evaluation, can we try to discuss the problems like mass generation. Then, as mentioned in previous section, the phase transition of vacuum will occur. The number of degrees of freedom N in the environment of a particle is not a large number, but N$\rightarrow\infty$. An elementary example is the geometric series: $S_n = 1 + r + r^2 + \cdots + r^n$ is essentially different from $\lim_{n\to\infty} S_n = (1-r)^{-1}$.

We believe that $L \rightarrow \infty$, $N \rightarrow \infty$, this is the difficult problem in theoretical physics challenging us. We are always facing the dilemma that "the world is infinite while our knowledge remains finite". Hence it is inevitable that every theoretical model is limited to its boundary of applicability, where some singularity is destined to emerge, e.g., the black hole in general relativity. If a theory really gets rid of any singularity, it must be trivial in the sense of being meaningless or even wrong, just like what said by the famous Liouville theorem in the complex variable function theory.

7. "We are actors, and spectators as well"

Finally, I don't think that the basic research of physics in the next century will enjoy more brilliant achievement than that gained in the 20th century. The reason is plain: the majority of basic laws governing the existing matter on the earth seems comparatively clear. However, the applications of physics, the combination of physics with other science and technology, especially astronomy and life science, are just in blooming. During this process we will discover the harmony form large cosmos to tiny world. We will face the infinite world consciously and cognize ourselves more consciously. As Weisskopf said [20], we, who are living in the 20th century, are privileged to witness the most exciting phase in the evolution process of living beings. It is on the earth the greatest adventure of the universe takes place — that nature in the form of man begins to understand itself. Once upon a time, Bohr said:" In searching for the harmony of life, one should never forget that in the drama of existence, we ourselves are actors, and spectators as well". While there are so many challenges facing our mankind, let us unite and work together for a better world in the next century.

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